Advanced Computer Networks

Network Topology

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Motivation

- Knowing network topology is important
  - network planning
  - traffic engineering
  - performance evaluation
  - protocol design
  - ...

Reality check

- Network topology is difficult to obtain
  - Internet-scale
  - at application, IP, domain, router levels
  - business disincentive
- Measuring network topology is difficult
  - AS topology
    - BGP updates: path vector abstraction
  - router topology
    - traceroute
    - alias resolution, measurement bias

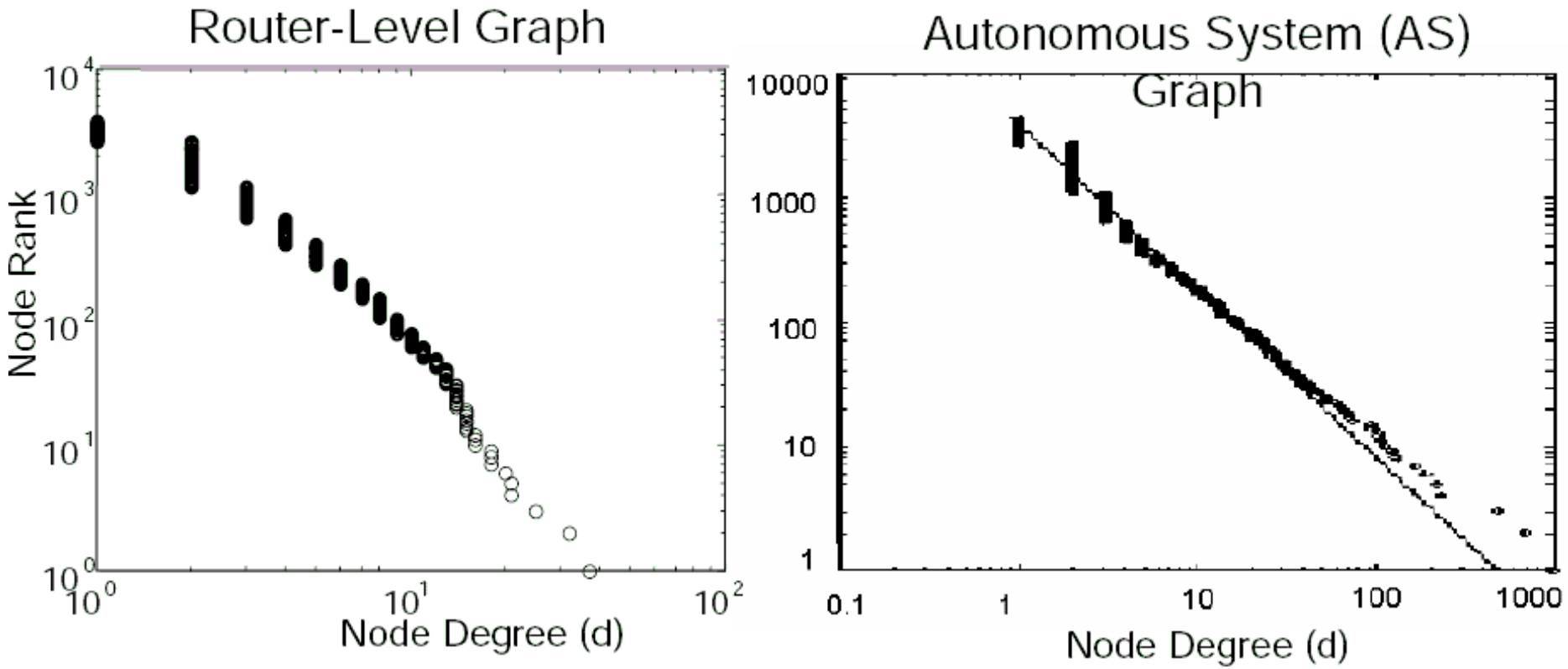
Observations

- Long-distance links are more expensive
  - locality
  - Waxman random graph (1988)
- Tiered Internet structures
  - hierarchy
  - GT-ITM structure graph (1996)
- Power-law degree distribution (1999)
  - preferential attachment
  - degree-based random graph: PA, expected degree

Power-law distribution

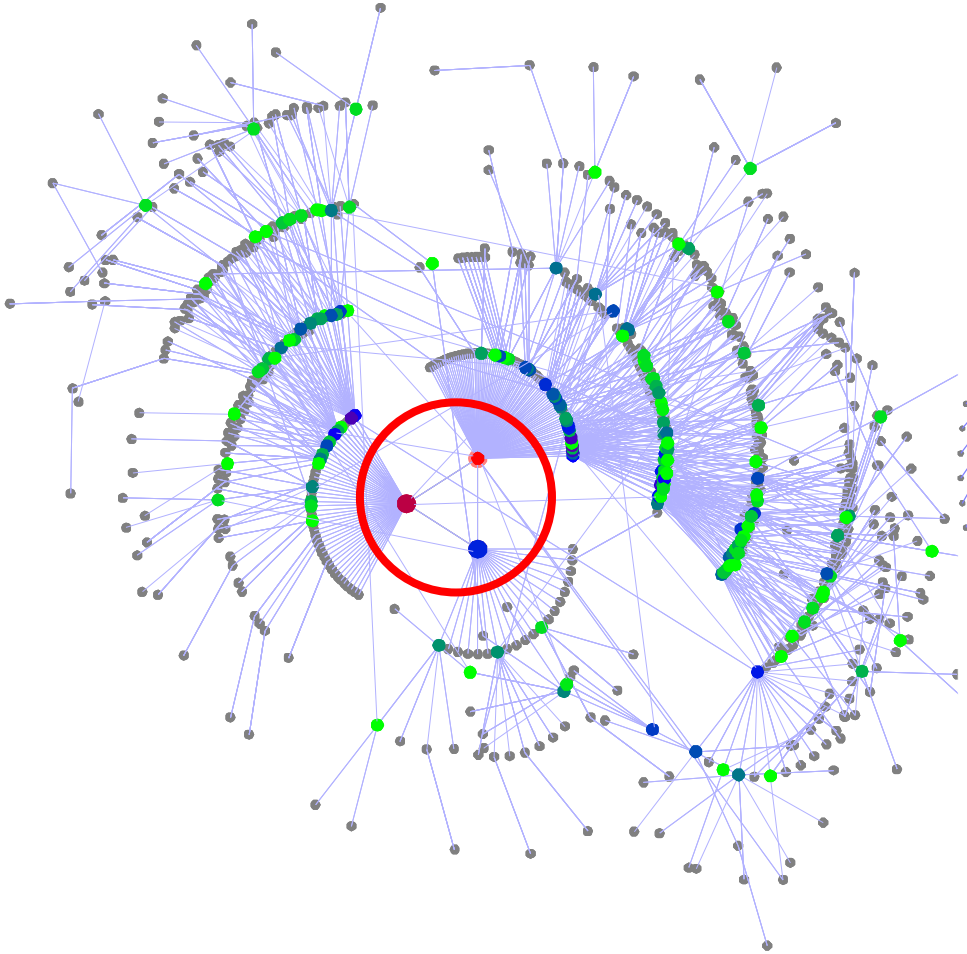
- At both router and AS levels

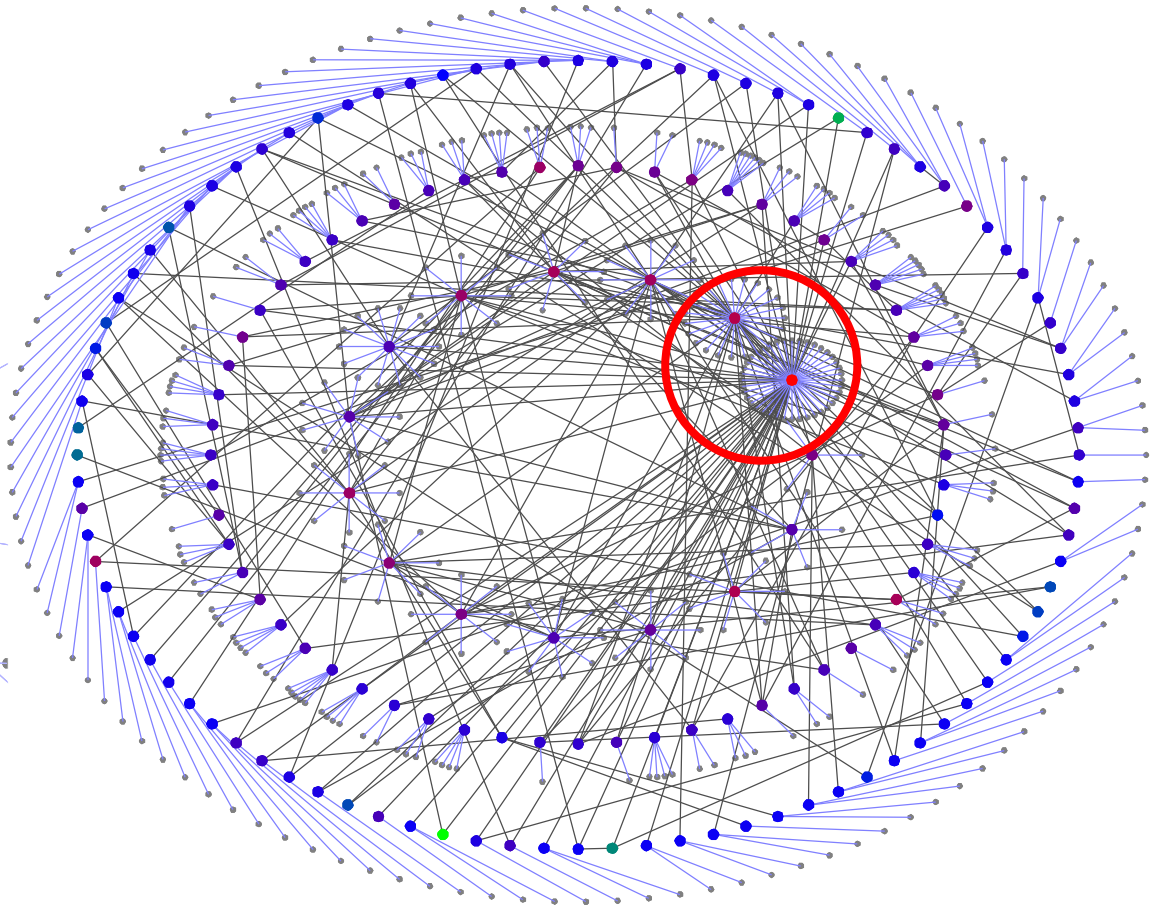
Source: Faloutsos et al. (1999)



Features of degree-based models

- Preferential attachment vs expected degree





e.g., PLRG, GRG

New approaches

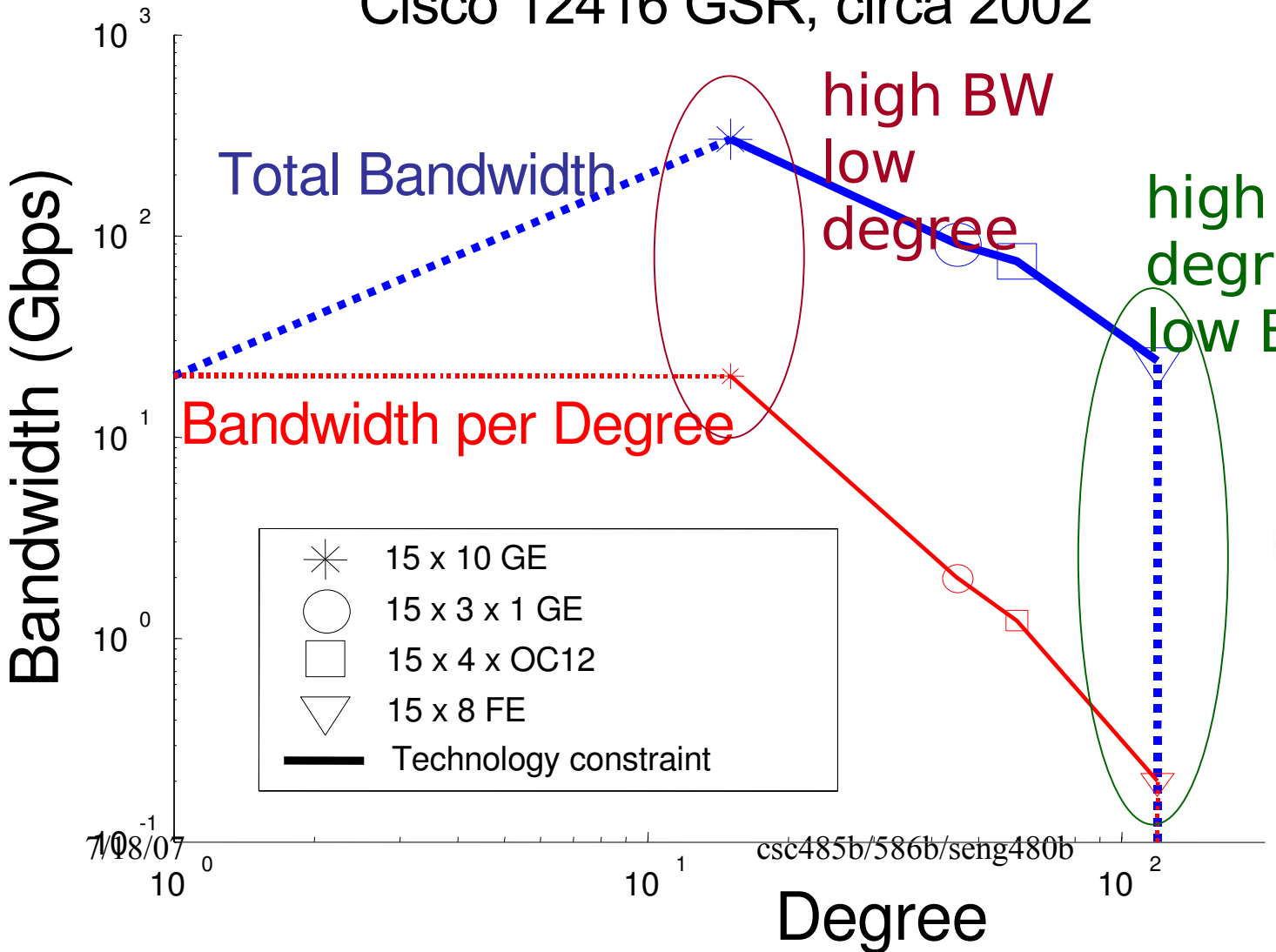
- First-principles approach
  - [LAWD04] Lun Li, David Alderson, Walter Willinger, John Doyle. A First-Principles Approach to Understanding the Internet's Router-Level Topology. In SIGCOMM 2004. (Best student paper)
  - Follow-on work:D Alderson, L Li, W Willinger, JC Doyle. Understanding Internet Topology: Principles, Models, and Validation. IEEE/ACM TRANSACTIONS ON NETWORKING, Dec. 2005.

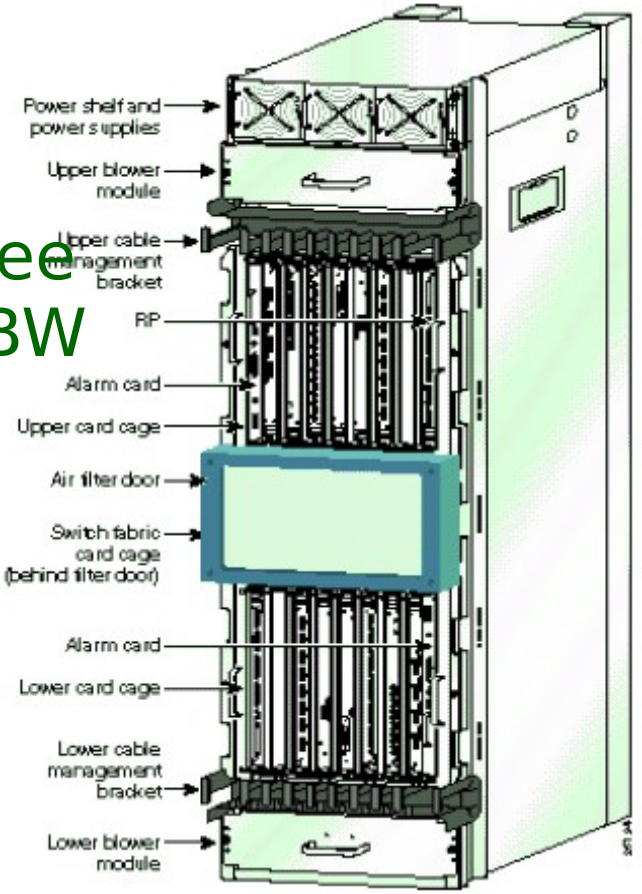
http://hot.caltech.edu/topology.html

First-principles approach

- Technology constraints

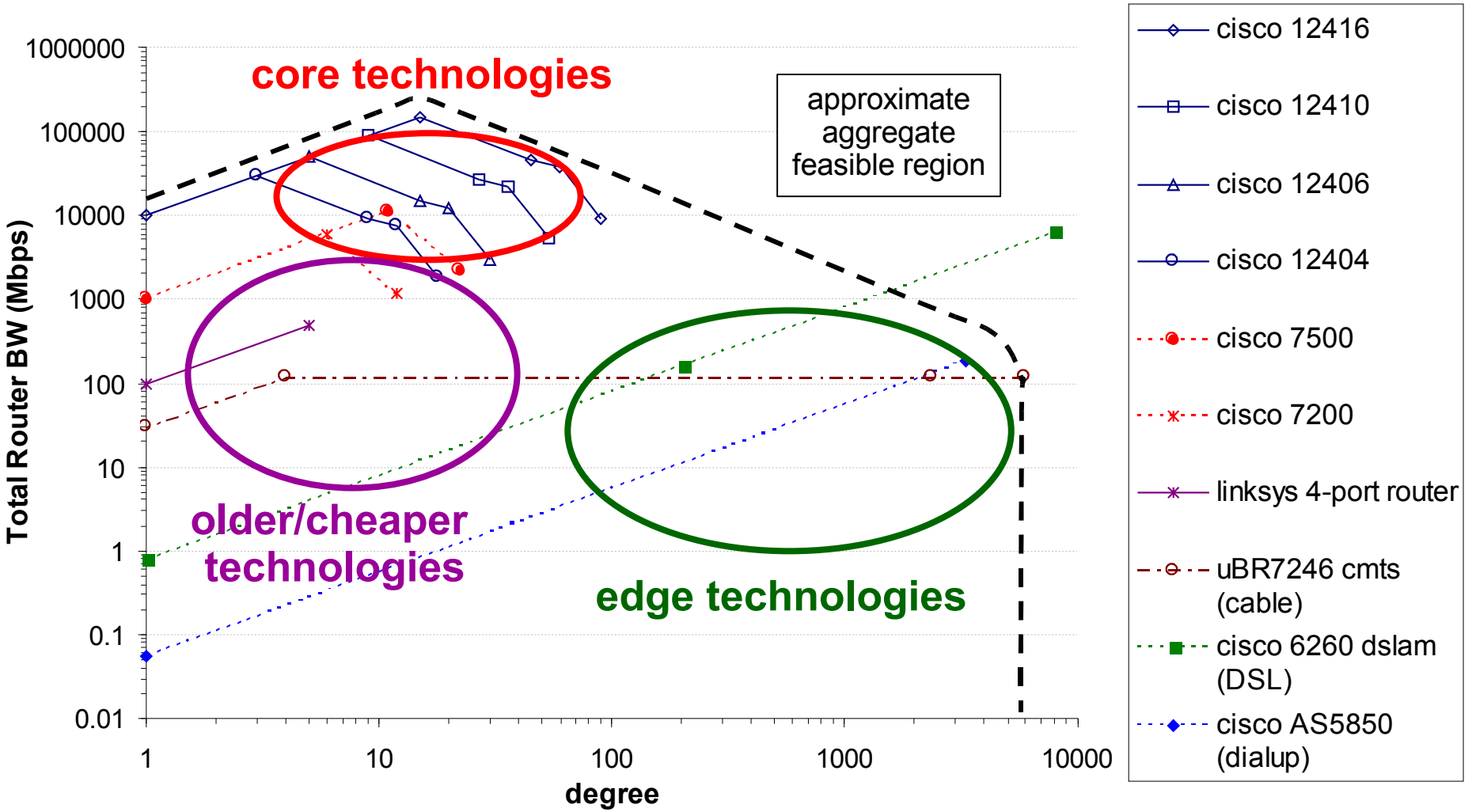
Cisco 12416 GSR, circa 2002





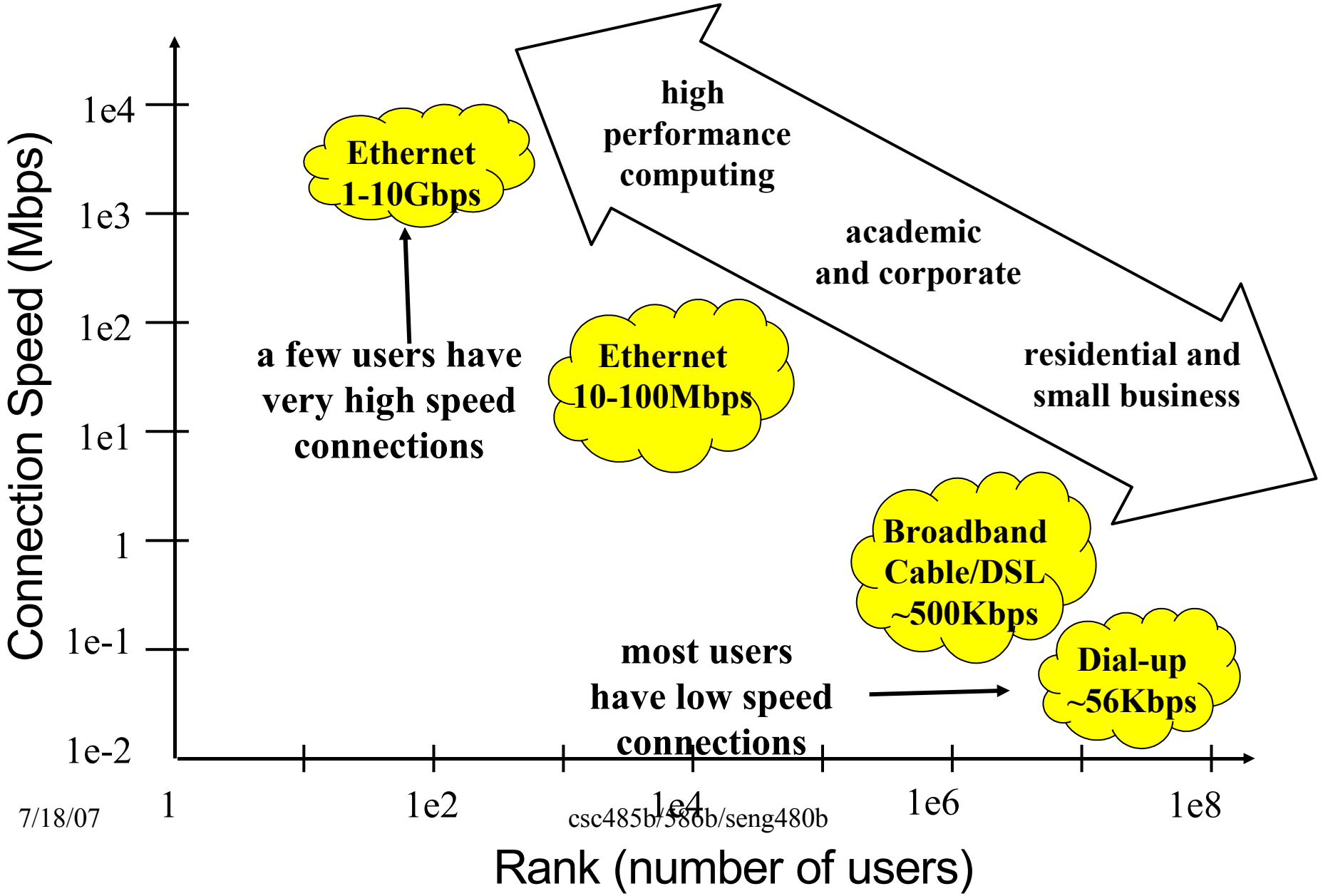
Q: why such constraints?

Technology constraints

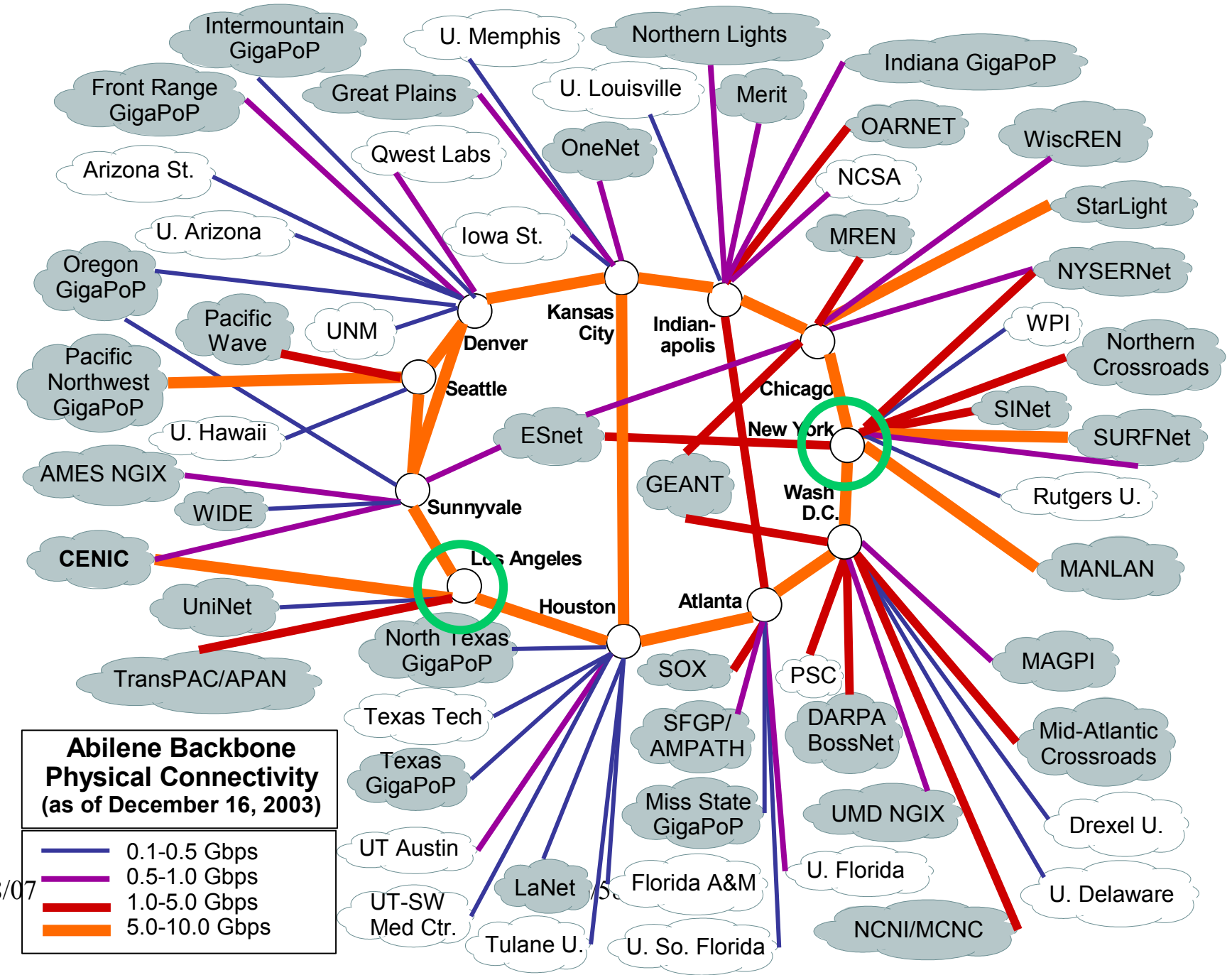


Source: Cisco Product Catalog, June 2002

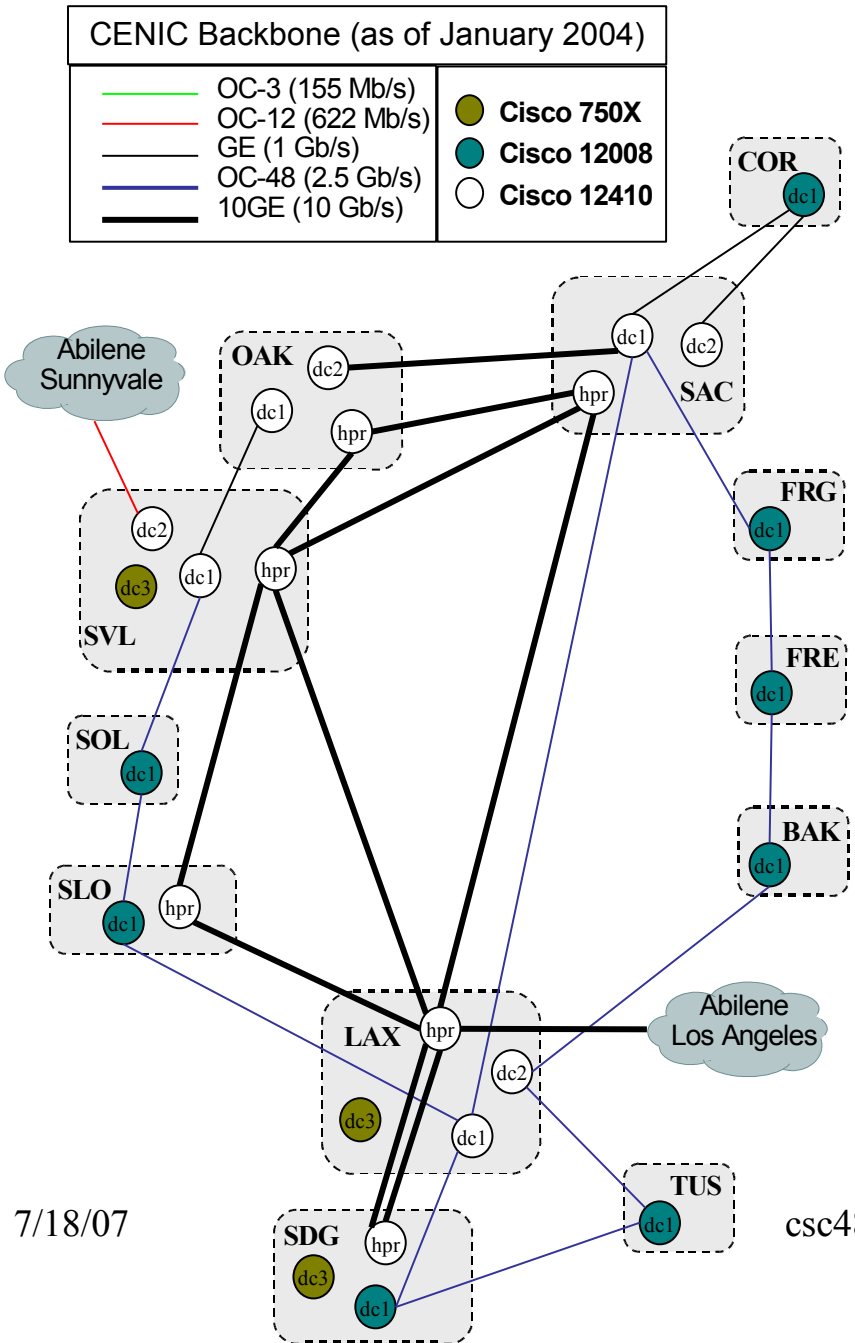
Economy constraints



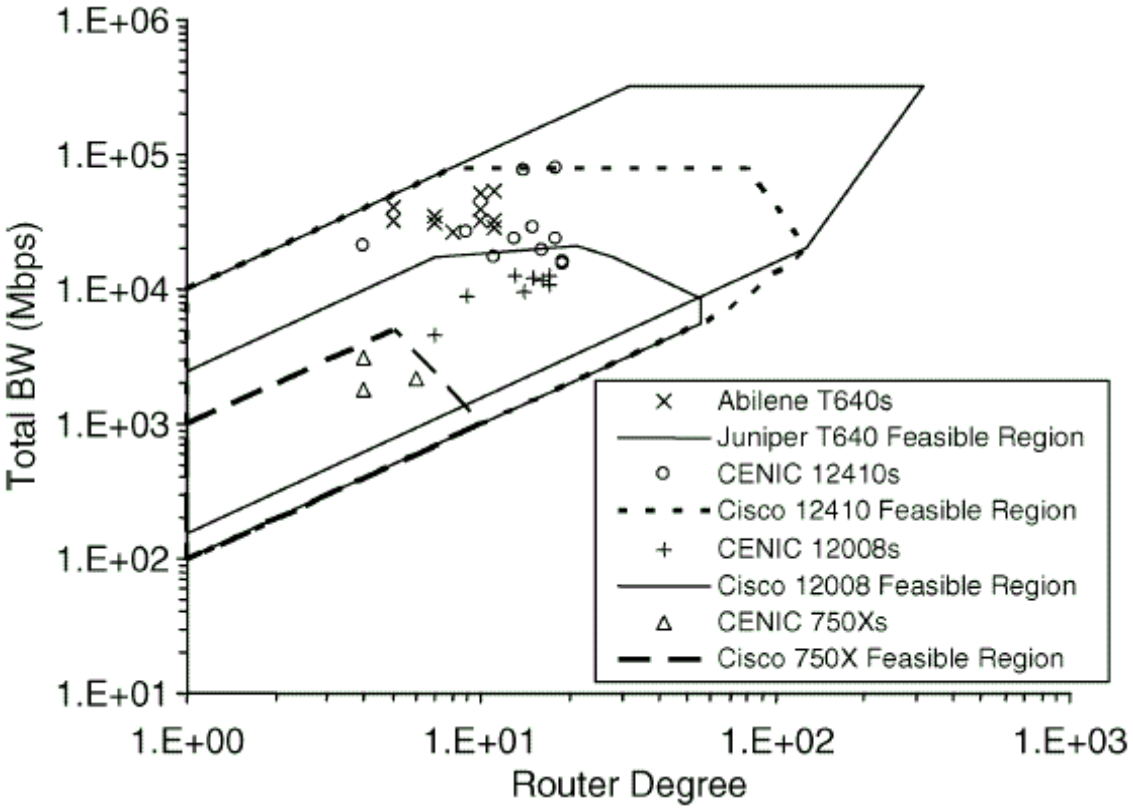
Evidence: Internet2/Abilene



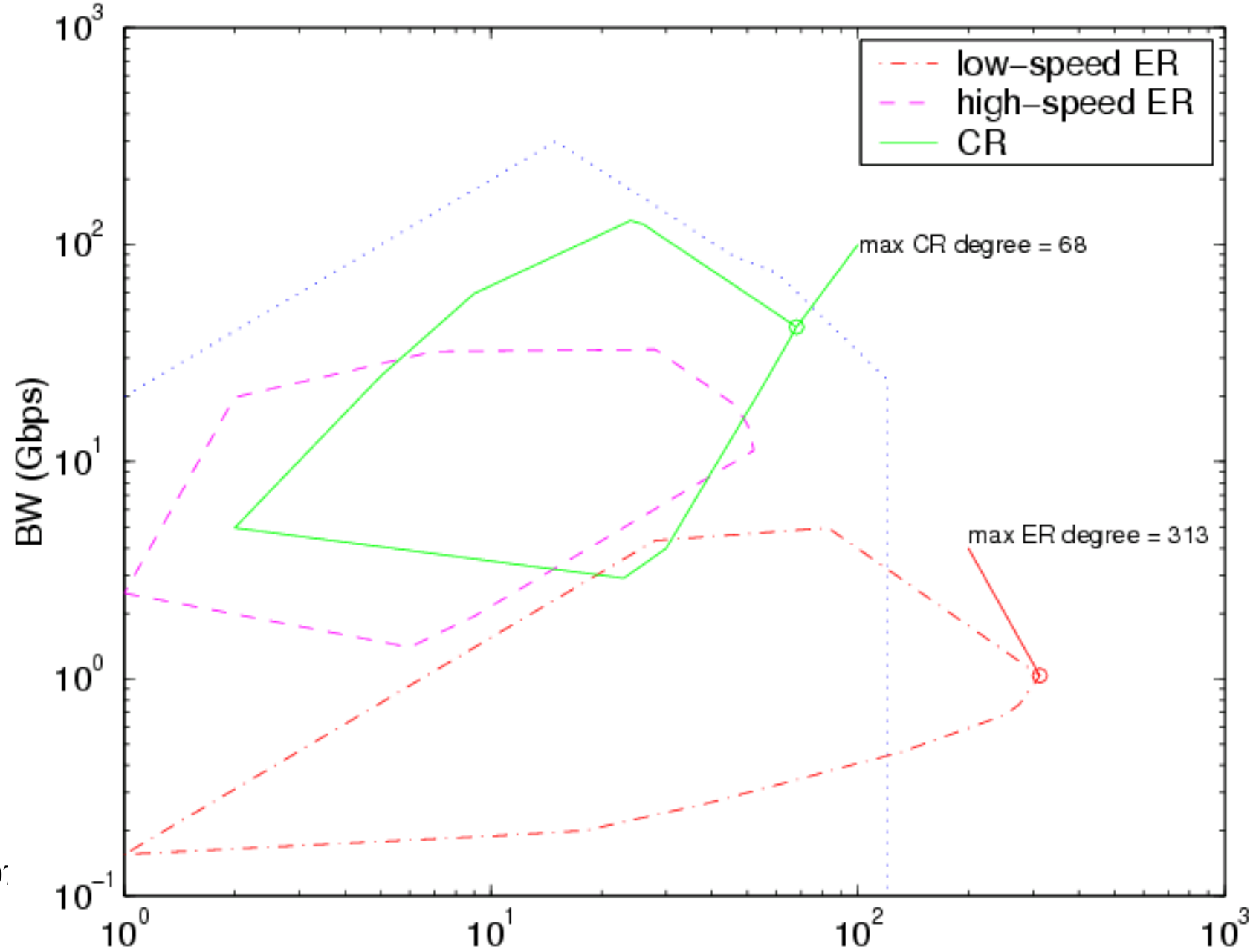
CENIC


CENIC Backbone (as of January 2004)
OC-3 (155 Mb/s)
OC-12 (622 Mb/s)
GE (1 Gb/s)
OC-48 (2.5 Gb/s)
10GE (10 Gb/s)
Cisco 750X
Cisco 12008
Cisco 12410
COR
dc1
SAC
dc1
dc2
hpr
OAK
dc2
dc1
hpr
Abilene
Sunnyvale
FRG
dc1
SVL
dc2
dc3
dc1
hpr
FRE
dc1
SOL
dc1
BAK
dc1
SLO
dc1
hpr
LAX
hpr
dc2
dc3
dc1
Abilene
Los Angeles
TUS
dc1
SDG
hpr
dc3
dc1

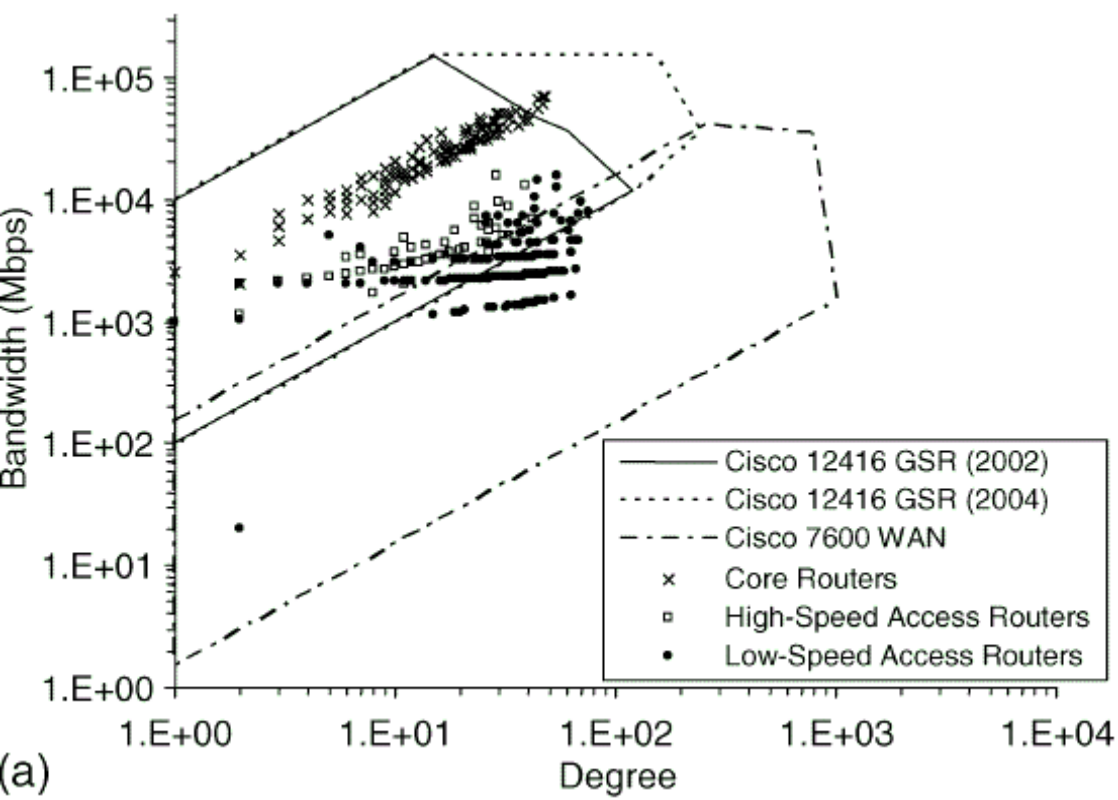

Corning
Sacramento
Oakland
San Francisco
Merced
Palo Alto
San Jose
Fresno
Bakersfield
Riverside
Palm Desert
El Centro


Total BW (Mbps)
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E+01
1.E+02
1.E+03
Router Degree
Abilene T640s
Juniper T640 Feasible Region
CENIC 12410s
Cisco 12410 Feasible Region
CENIC 12008s
Cisco 12008 Feasible Region
CENIC 750Xs
Cisco 750X Feasible Region

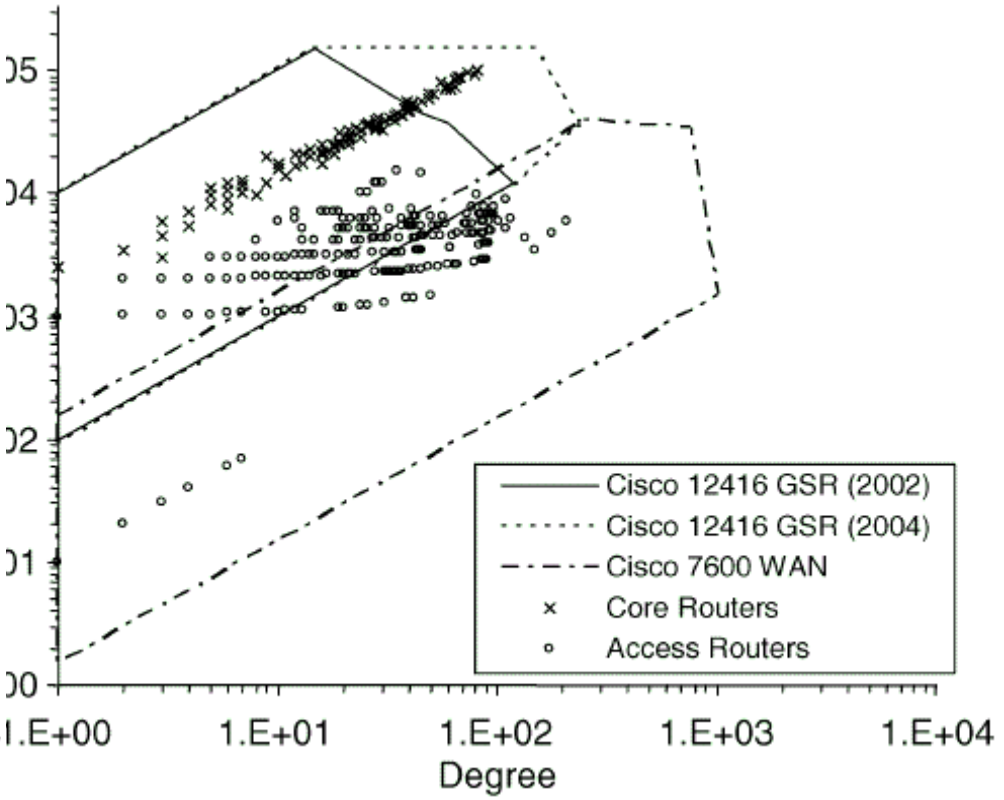
AT&T


low–speed ER
high–speed ER
CR
max CR degree = 68
max ER degree = 313
BW (Gbps)
10^3
10^2
10^1
10^0
10^{-1}
10^0
10^1
10^2
10^3

Rocketfuel-inferred



AT&T

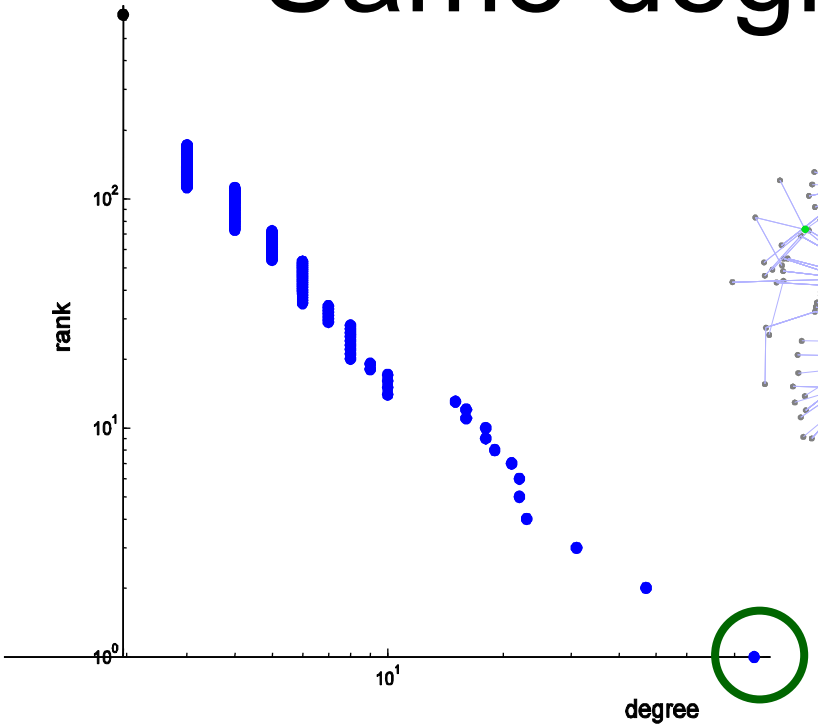


Sprint

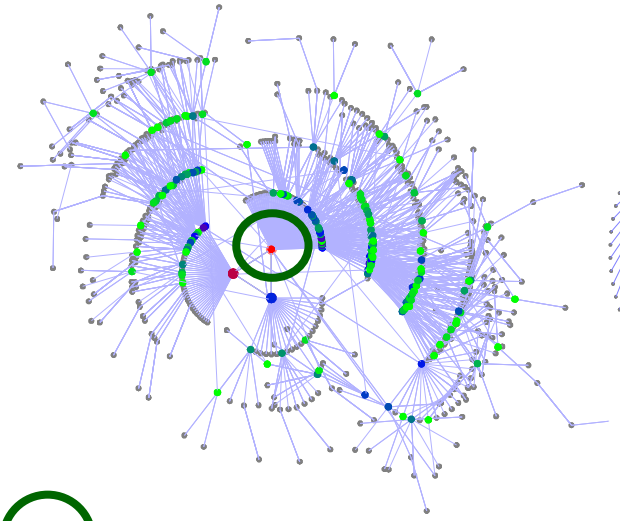
Comparison

- Degree-based approach
  - follow a given degree distribution
  - power-law: high-degree central hubs
- First-principles approach
  - technology, economy constraints
  - others: geography, population constraints?
  - Heuristically Optimized Topologies (HOT)
    - faster low-degree backbone networks
    - slower high-degree access networks
  - consistent with real networks

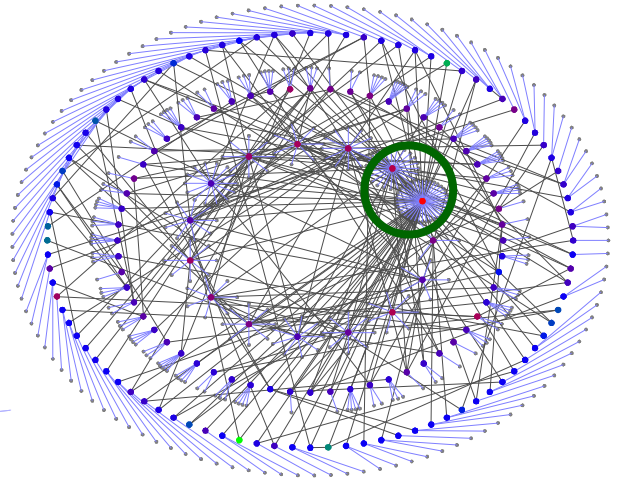
Same degree distribution...

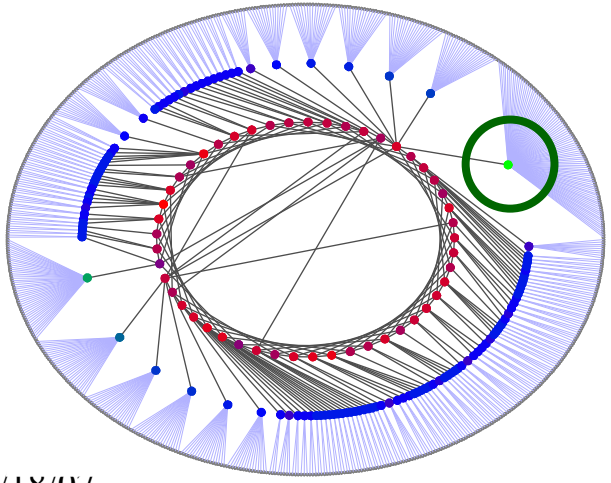


PA

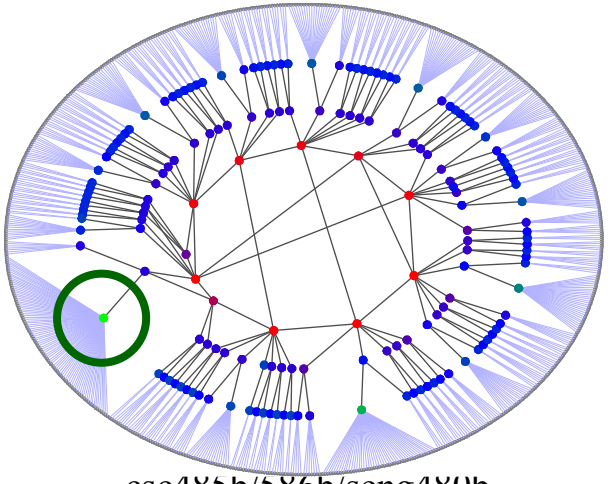


PLRG/GRG

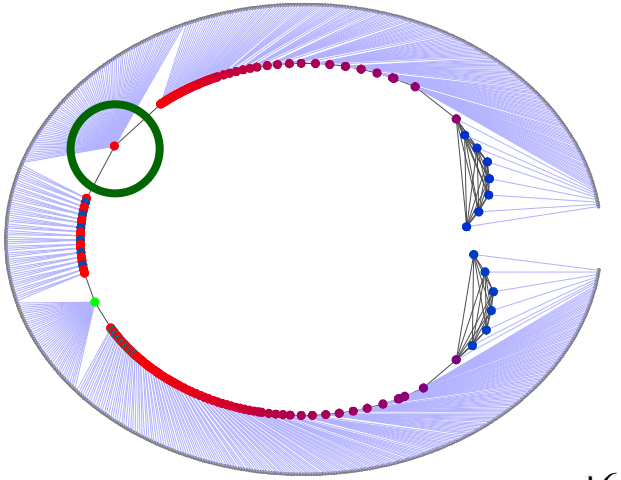




HOT



Abilene-inspired

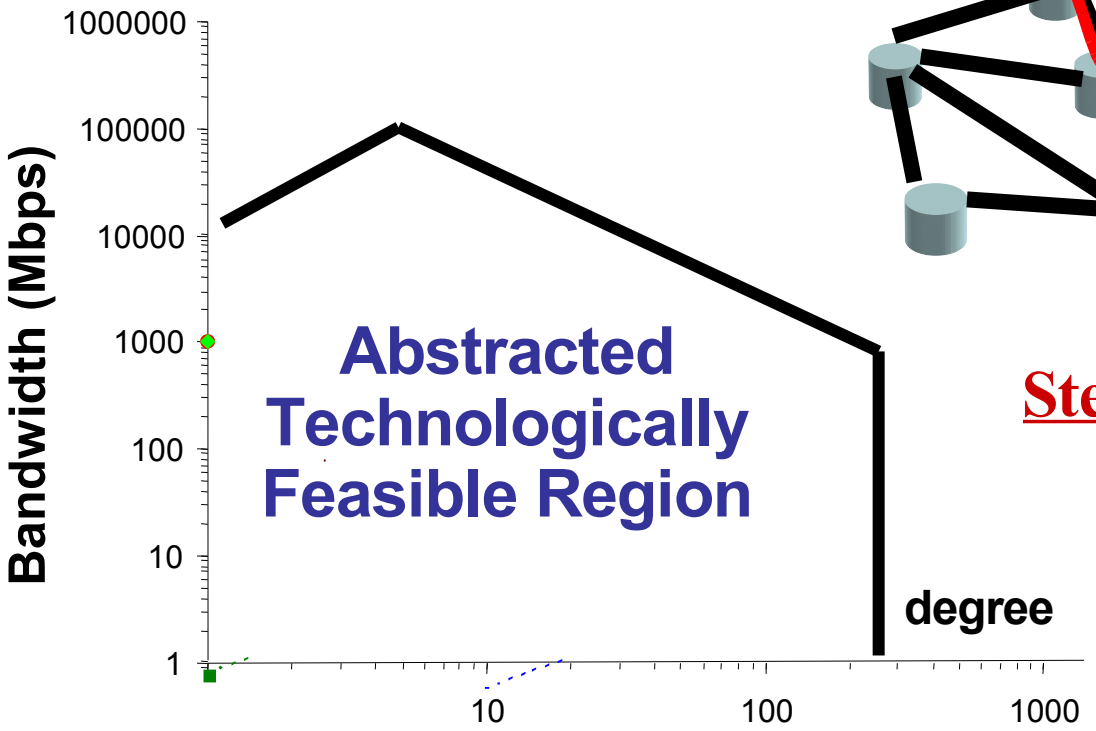


Sub-optimal

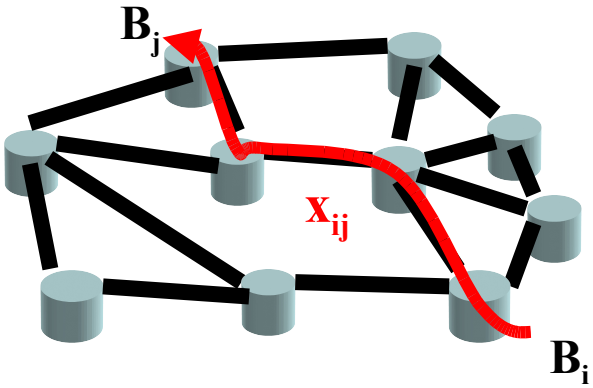
Network Performance

Given realistic technology constraints on routers, how well is the network able to carry traffic?

Step 1: Constrain to be feasible



Step 2: Compute traffic demand



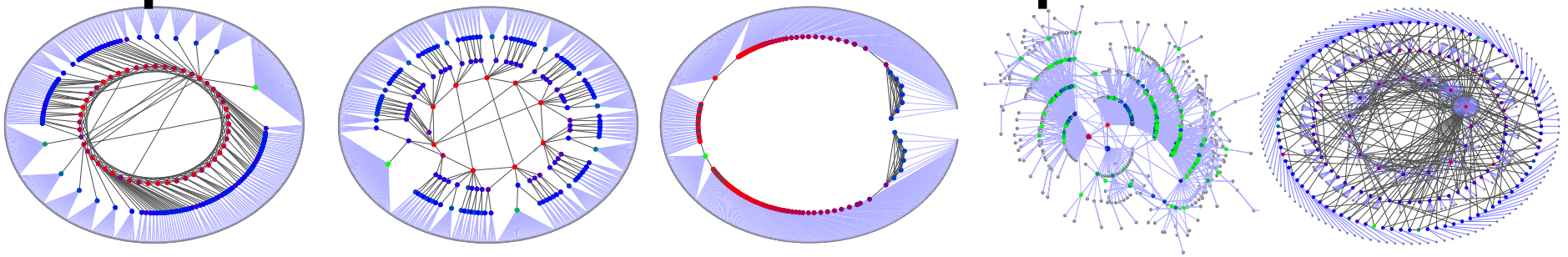
$$x_{ij} \propto B_i B_j$$

Step 3: Compute max flow

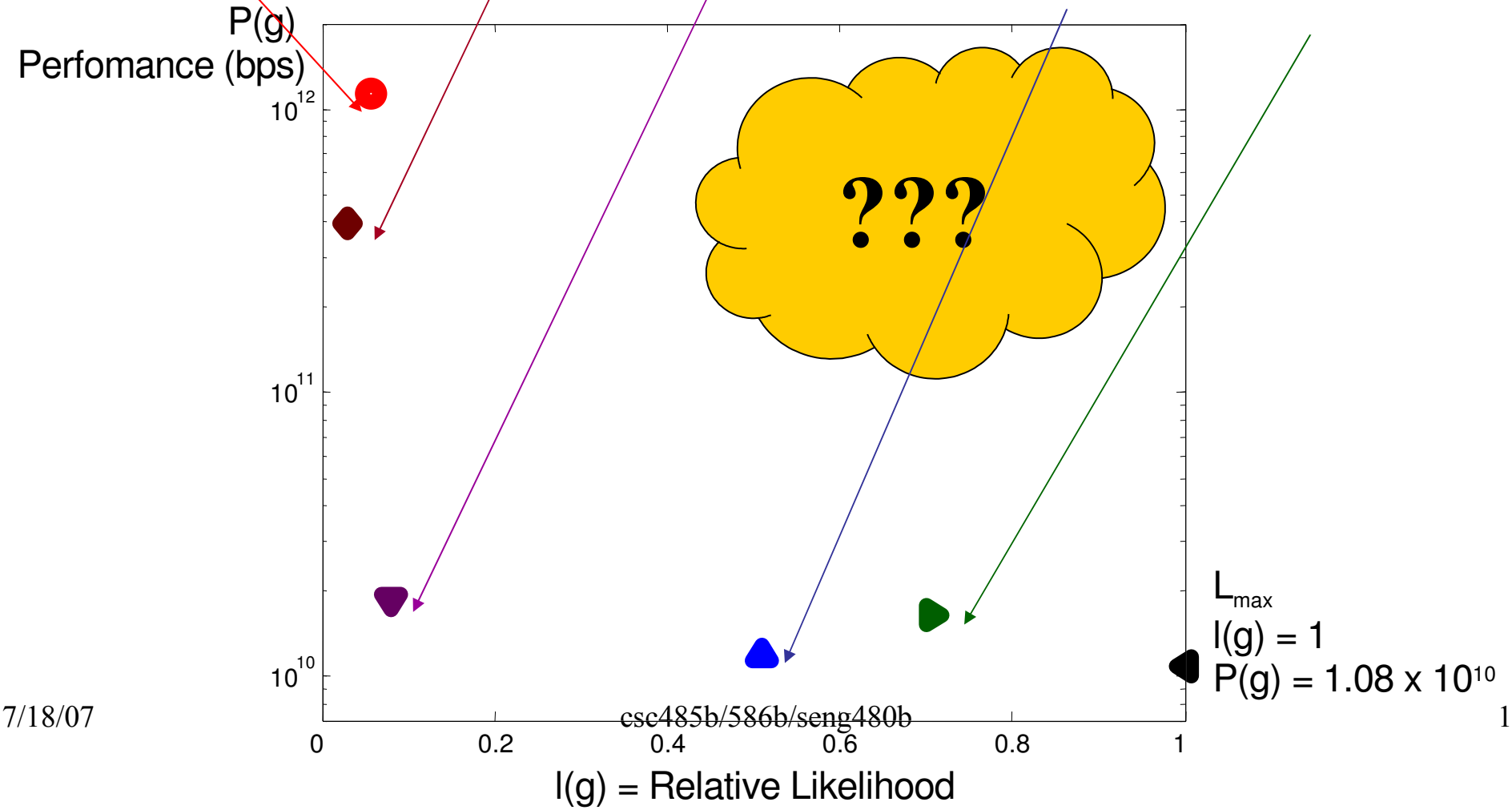
$$\max_{\alpha} \sum_{i,j} x_{ij} = \max \sum_{i,j} \alpha B_i B_j$$

$$s.t. \sum_{i,j:k \in r_{ij}} x_{ij} \le B_k, \forall k$$

Implication on network performance



HOT | Abilene-inspired | Sub-optimal | PA | PLRG/GRG



This lecture

- Topology modeling
  - probabilistic random graph
  - structure-based
  - degree-based
  - first-principles
    - technology and economy constraints, reality check
    - impact on network performance
- Explore further
  - http://hot.caltech.edu/topology.html
  - http://www.caida.org/workshops/isma/0605/

Next lectures

- July 23: guest lectures

- July 25, July 30, August 1
  - Course projects presentation

- Course evaluation: now!

One more message...

- Research opportunities for undergraduates
  - NSERC USRA
  - MITACS internship, on-campus coop
  - directed studies, technical projects
- Graduate study at UVic
  - UVic CS: systems, theory, applications
  - UVic ECE: communications networks, ...
  - financial support
    - NSERC CGS/PGS, BC Pacific Century, UVic Fellowship
    - research and teaching assistantship, coop